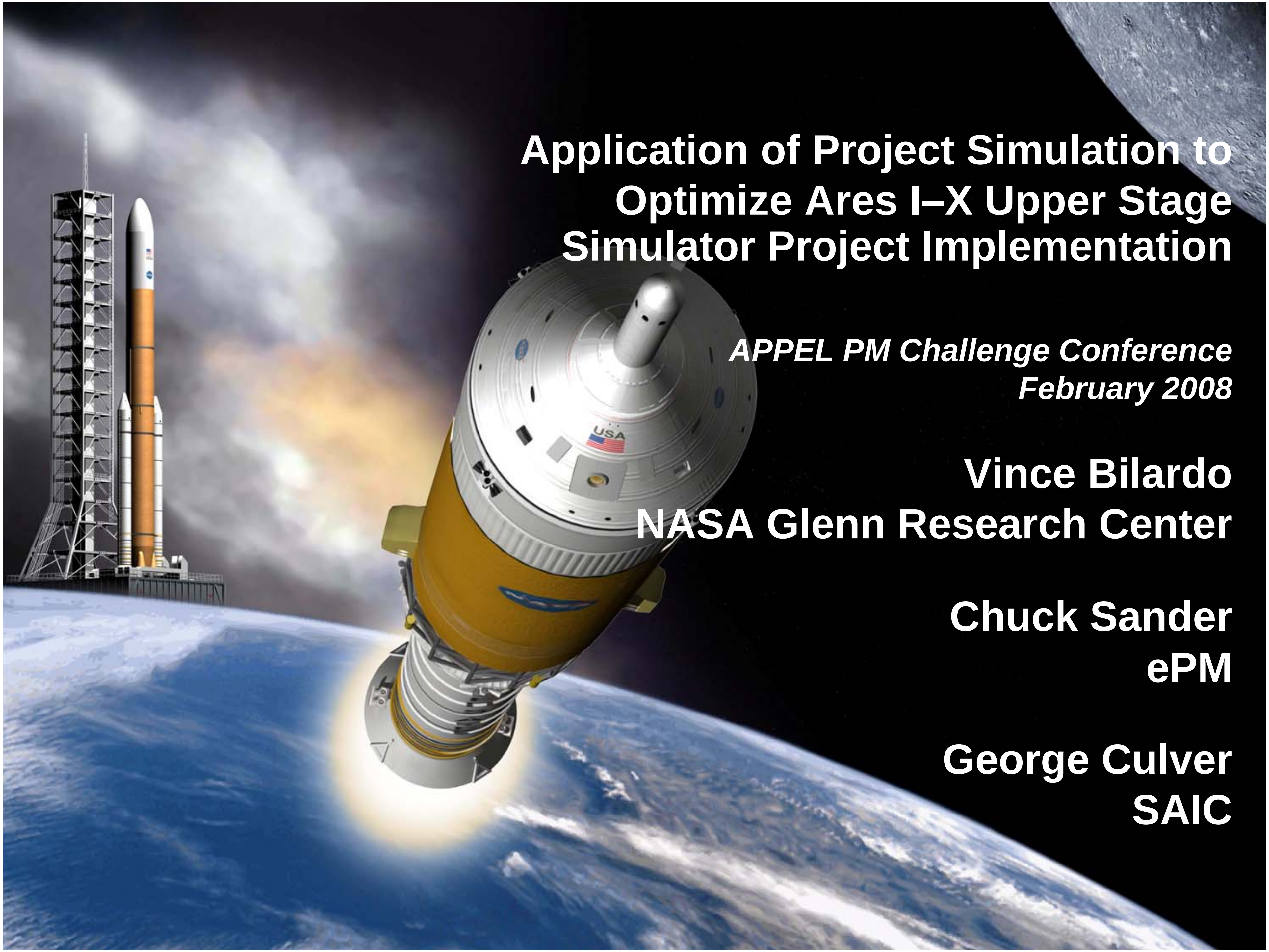

Application of Project Simulation to Optimize Ares I–X Upper Stage Simulator Project Implementation

APPEL PM Challenge Conference
February 2008

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Ares I-X Mission – First Ares I Test Flight!

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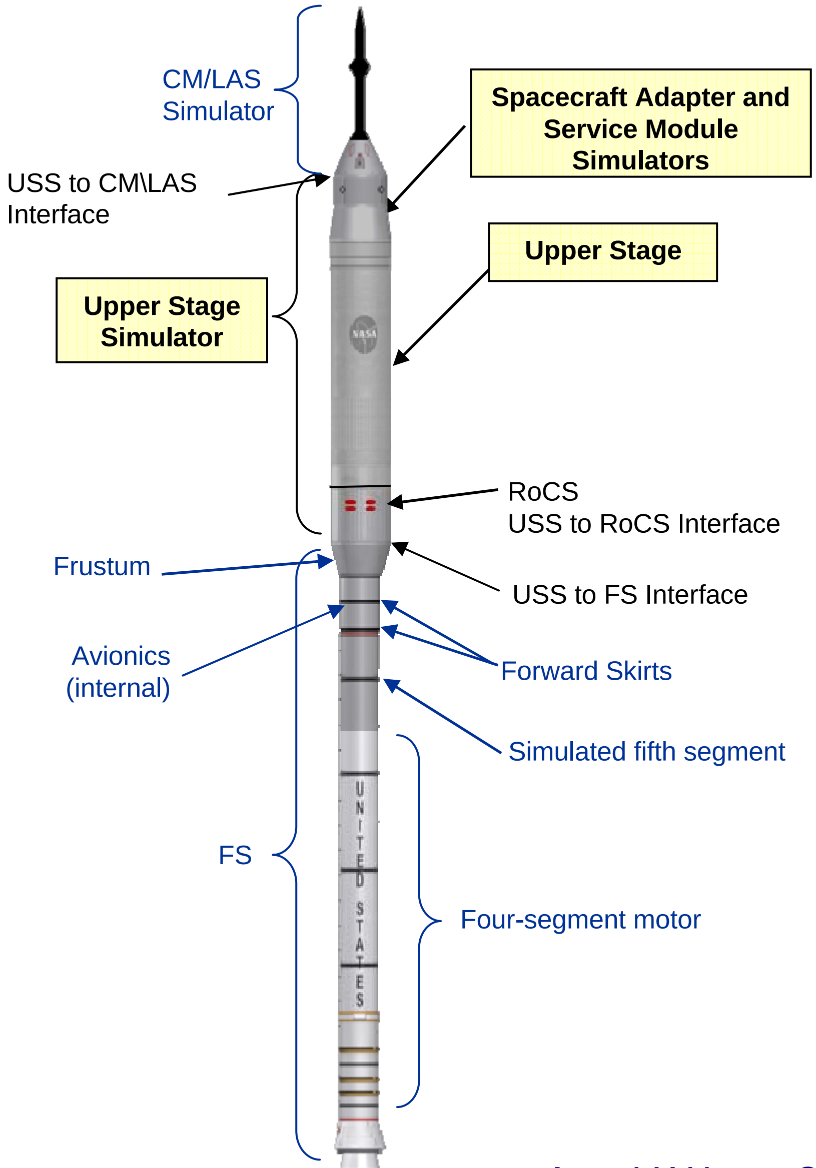
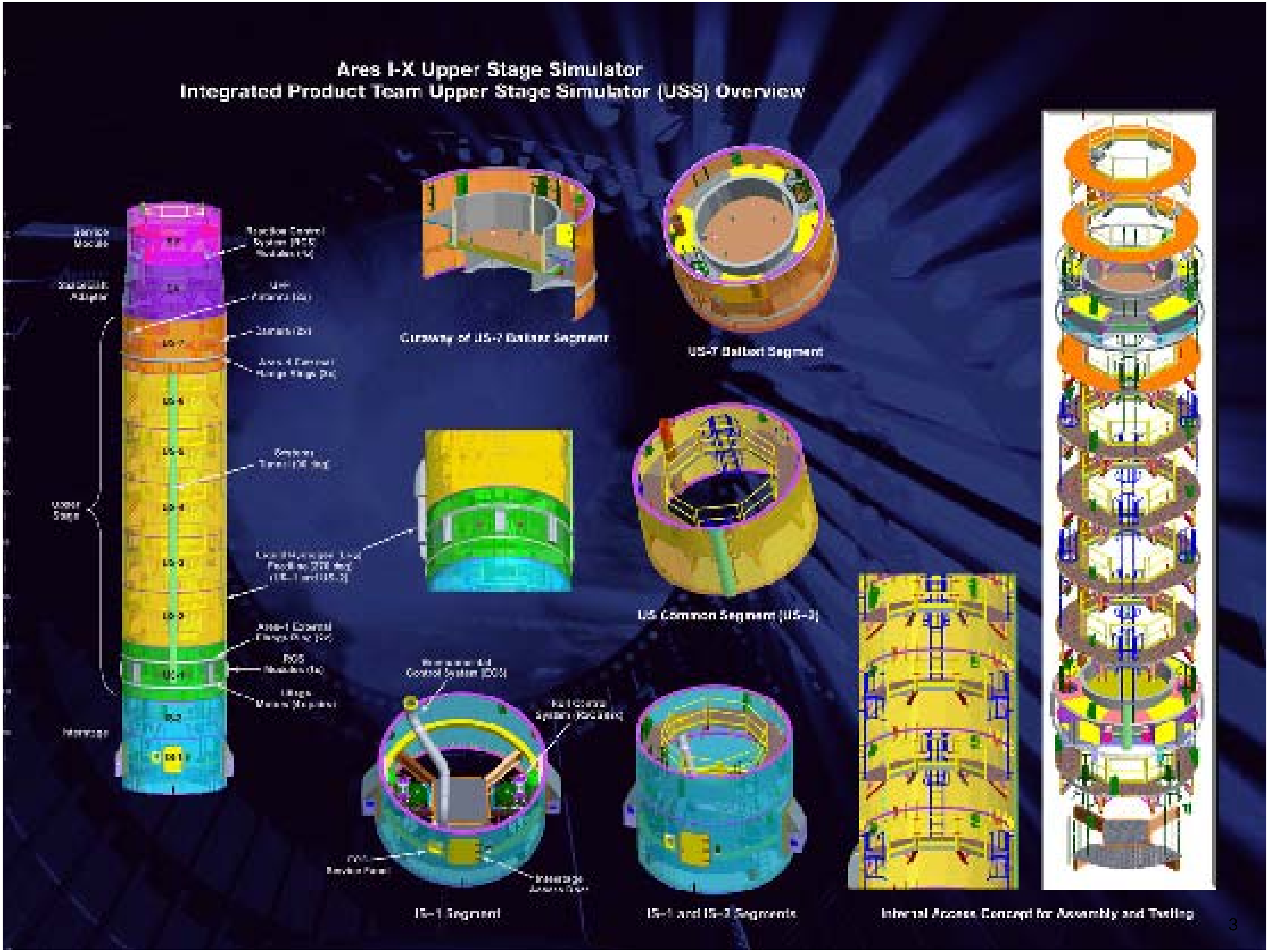


Ares I-X Upper Stage Simulator Team


Ares I-X Upper Stage Simulator
Integrated Product Team Upper Stage Simulator (USS) Overview
Cutaway of US-7 Ballast Segment
US-7 Ballast Segment
US Common Segment (US-3)
IS-1 Segment
IS-1 and IS-2 Segments
Internal Access Concept for Assembly and Testing

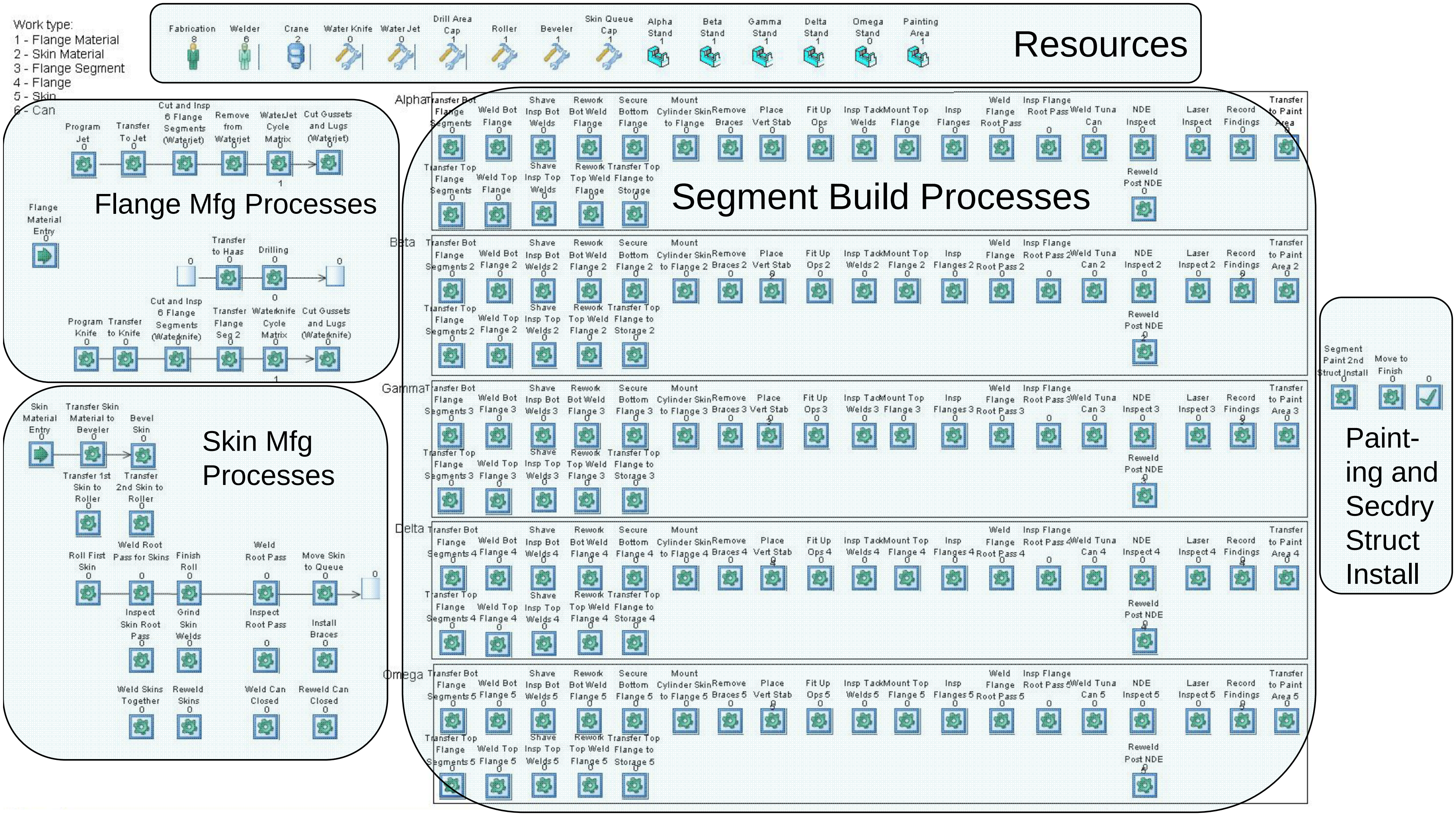
Purpose of Analysis

1. **SAIC and ePM were tasked to investigate the Upper Stage Simulator manufacturing processes.**
   a. ePM looked organizationally across entire manufacturing process.
   b. SAIC focused on manufacturing process details in GRC's Ares Manufacturing Facility (AMF).

2. **Following approach was used by both teams to conduct analysis:**
   a. Solicited and received process flow and resource use data from customer (NASA USS Project Team).
   b. Used Simulation techniques to model process execution.
      1) ePM used organizational simulation techniques with NASA SimVision®.
      2) SAIC used SIMUL8 Discrete Event Simulation (DES) software.
   c. Iteratively revised models as process matured.
      1) NASA SimVision informing the DES model and vice versa.
      2) Modeling workshops informed the project team and the modelers.

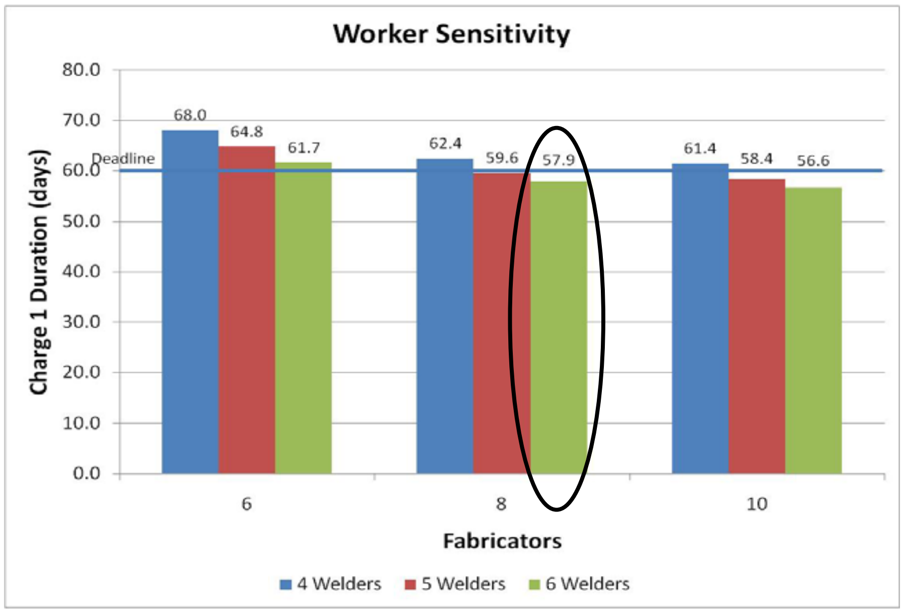
DES Model of USS Manufacturing Process

Segment manufacturing process modeled with SIMUL8 DES software.



Results: Sensitivity to Number of Workers

1. **Process is highly sensitive to changes in number of both fabricators and welders.**
2. **To meet deadline with minimum personnel, data suggests good baseline with:**
   a. 8 Fabricators per shift
   b. 6 Welders per shift



Fabri-cators	Welders	Charge Duration (days)
10	6	56.6
8	6	57.9
6	6	61.7
10	5	58.4
8	5	59.6
6	5	64.8
10	4	61.4
8	4	62.4
6	4	68.0

Each Charge duration reflects average of 50 independent trials

Investigation of Non-Destructive Inspection

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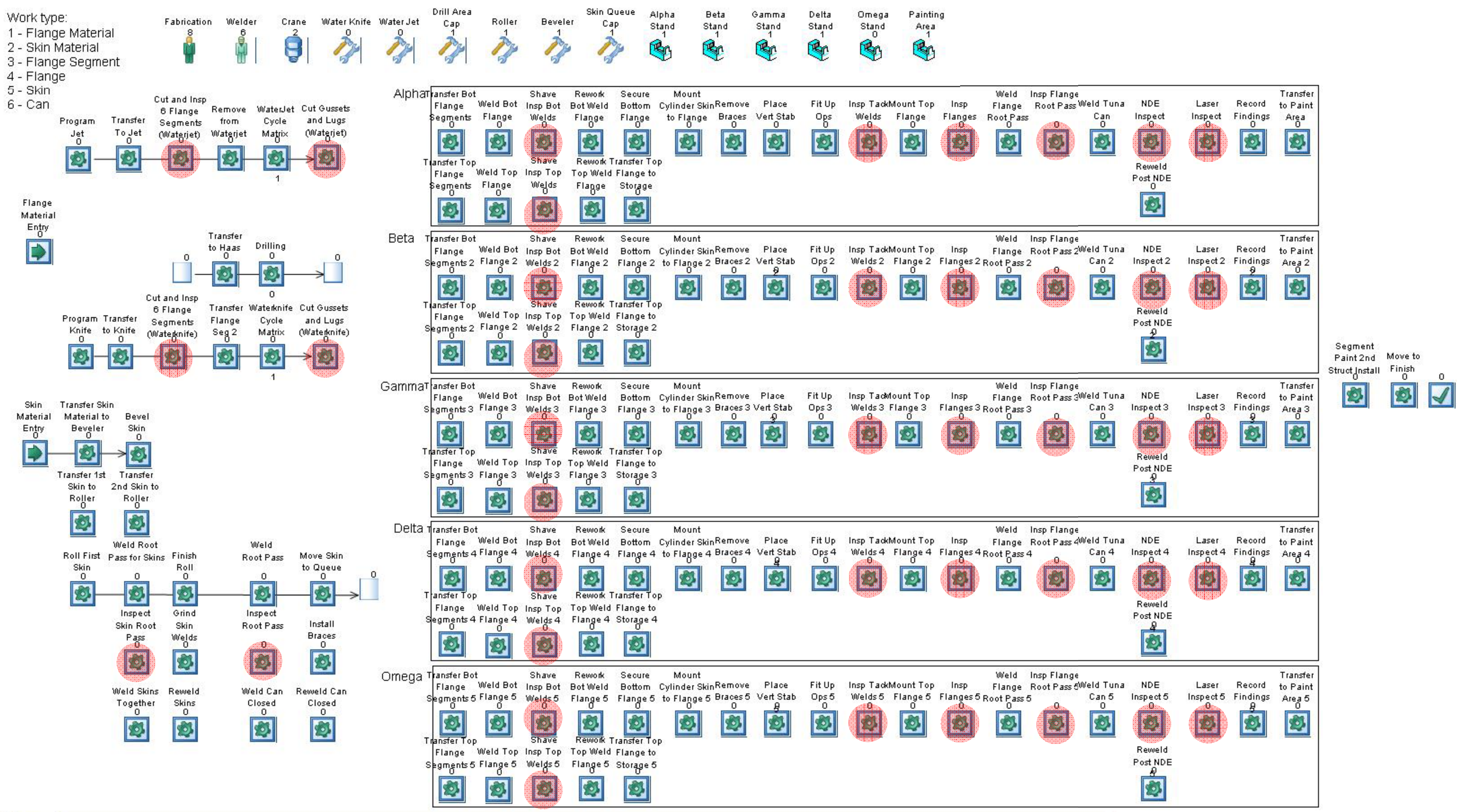
Mandatory Inspection Points (MIPs) highlighted.



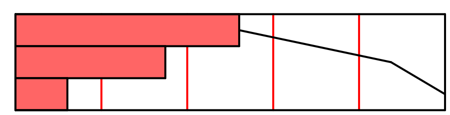
Results: NDE Inspection Sensitivities

1. **This sensitivity analysis assesses NDE defect rate, NDE repair time per defect, and NDE Inspection time.**
   a. Subsequent charts show specific sensitivities for each factor.
2. **Following results are average of 50 trials each of 72 cases obtained varying:**
   a. NDE defect rate between 0.1% and 10%.
   b. NDE repair time at 1, 2, 4, or 10 hours.
   c. NDE inspection time at 8, 24 or 40 hours.
3. **Aggregate results indicate Defect Rate is driving factor.**
   a. Tornado Plot below indicates Defect Rate has higher relative importance.
   b. Model-Fit of all data indicates Defect Rate has highest coefficient.

Relative Effect of Inputs on System Duration

Pareto Plot of Estimates

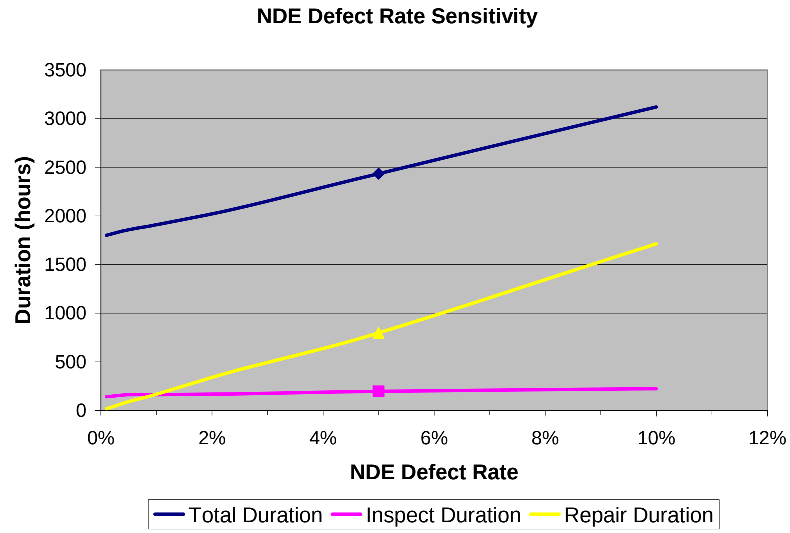
Term	t Ratio
NDEDefectRate	10.702772
NDERepairTime	7.211215
NDEInspectTime	2.517328

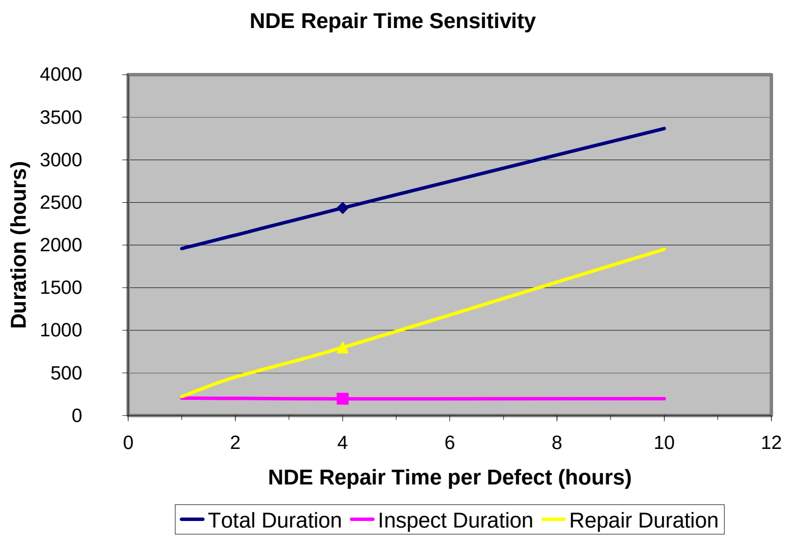


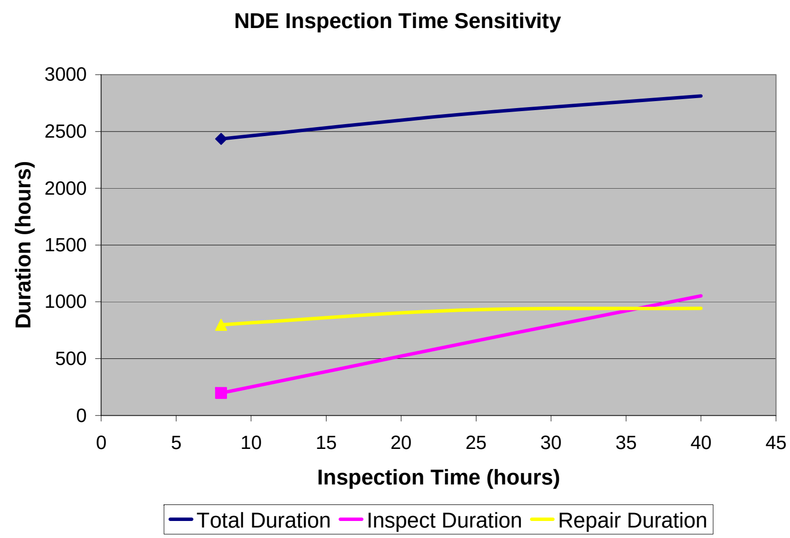
1. **System Duration is 1,193 hrs**
   + 159 hrs per defect percent
   + 106 hrs per NDE repair hour
   + 10 hrs per NDE inspection hour
2. **Defect rate affects the system duration more than the other variables.**

Result: NDE Sensitivities to Baseline

1. **These charts show impact of changing each NDE factor and holding others factors constant to their baseline.**
2. **Model Baseline includes:**
   a. NDE Defect Rate = 5%
   b. NDE Inspection = 8 hrs
   c. NDE Repair per Defect = 4 hrs
   d. Baseline shown with markers in each chart







DES Results and Conclusions

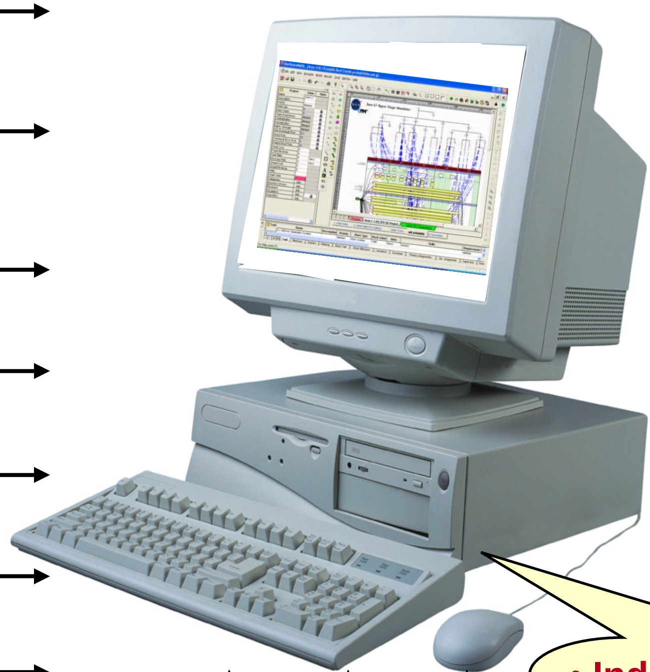
1. **Process is sensitive to number of fabricators and welders.**
    a. Suggested baseline using 8 fabricators and 6 welders per shift.
2. **Flanges, Gussets, & Lugs process matches closely to planned schedule when two full shifts are used.**
3. **Segment manufacturing Charges match closely to planned schedule when two full shifts are used.**
4. **Previous analysis has shown process is sensitive to NDE defect rate, NDE repair time, and NDE inspection time.**
    a. Each percent of NDE defect rate adds 159 hours to process duration.
    b. NDE Repair time increasing by 1 hour adds 106 hours to process duration.
    c. NDE Inspection time increasing by 1 hour adds 10 hours to process duration.

What SimVision® Does

Inputs

- Milestones
- Activities and Activity Characteristics
- Activity Dependencies
- Position Characteristics
- Organization
- Task Assignment
- Meetings
- Decision-Making Policy
- Communication Policy
- Organizational Dynamics

Model Simulation



- Individual behavior
- Organization theory
- Performance measures
- Discrete event simulation

Predictions

- Critical Path
- Project schedule
- Cost (Work, rework, wait, communication)
- Quality Risks (Work, communication)
- Position and people work load

SimVision permits effective front loaded project design by facilitating planning and organizational design with meaningful scenario analysis.

NASA SimVision® Model of USS Project

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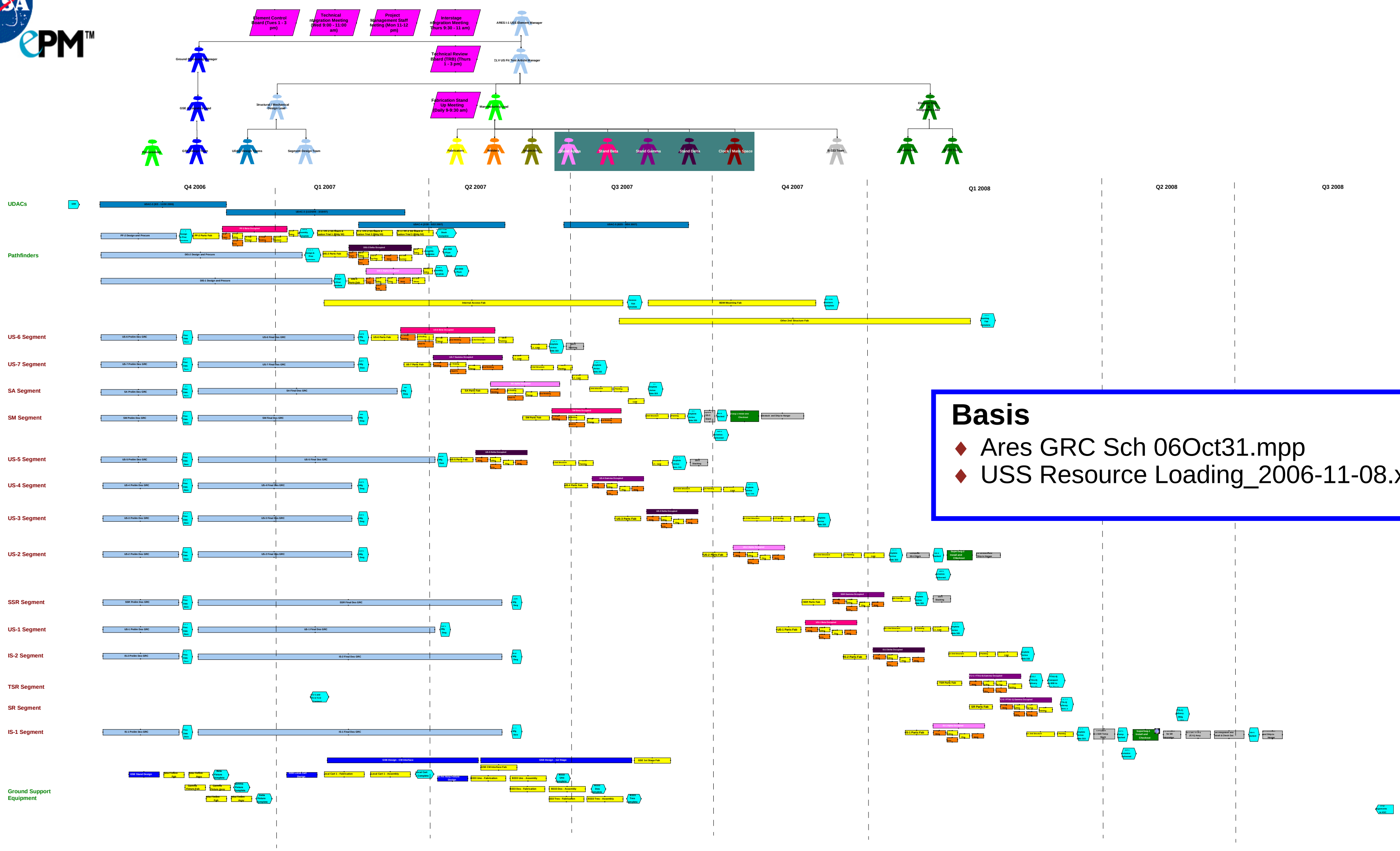

Basis

- Ares GRC Sch 06Oct31.mpp
- USS Resource Loading_2006-11-08.xls

Results: Baseline Simulation Case

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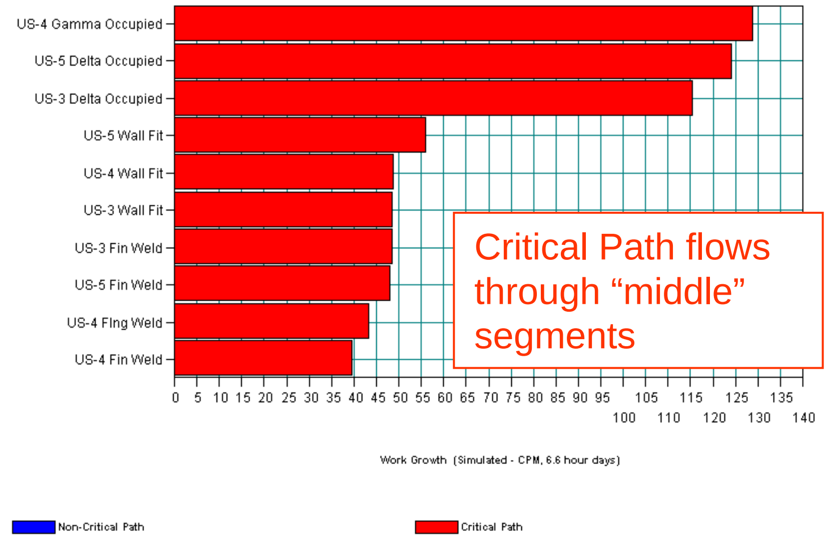
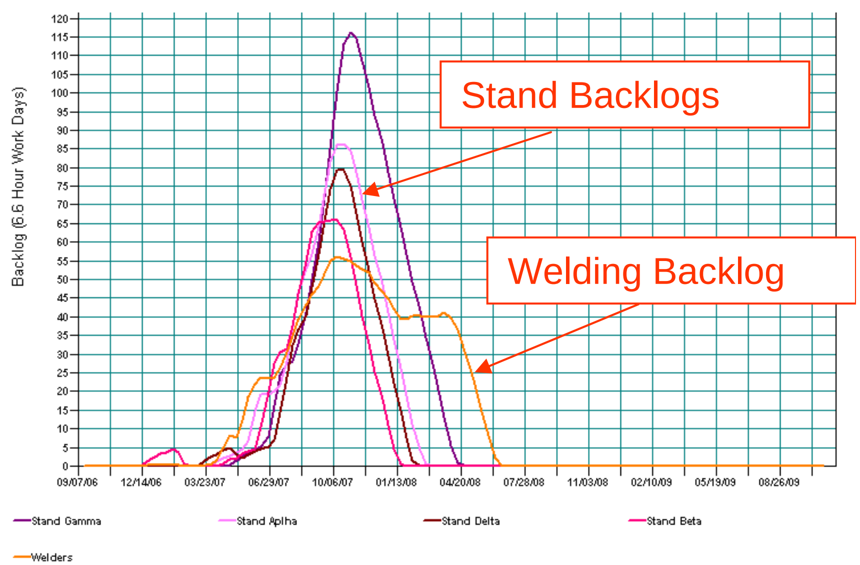
1. **Critical Path**
   a. Ship to KSC Date: **March 2009 – six months late!**
   b. PF’s / DIS’s miss completion dates.
   c. Preliminary Segment Designs are showing schedule pressure.
   d. Final Segment Designs show float.
2. **Organizational Impacts**
   a. Coordination effort is significant for integrative tasks (Rolling, Seg Fitup).
   b. Space/Stand **competition drives schedule delays.**
   c. Welding tasks present an opportunity to compress/recover schedule.
   d. Welders and Fabricators experience > **1 month** backlog (up to 6 welders and 16 fabricators required during peak periods).



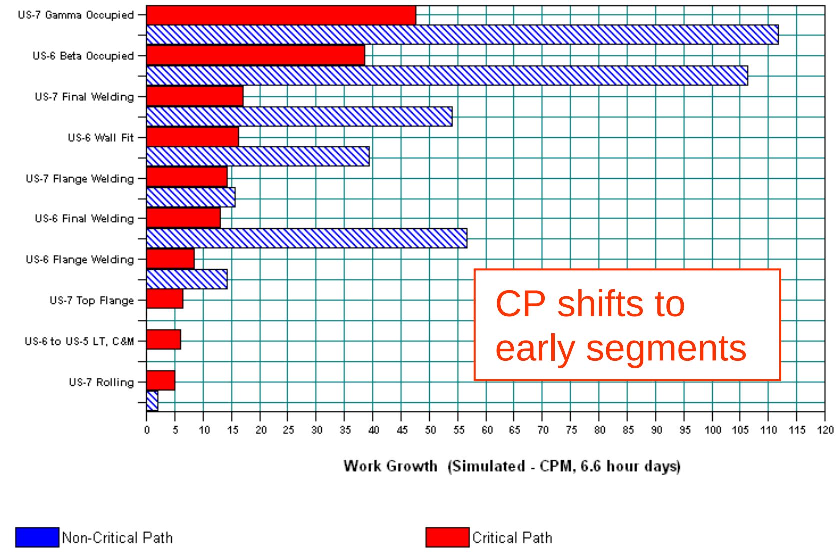


Conclusions

a. Accelerate Preliminary Designs and Final Designs for early Segments (e.g., US-2/3/4/6/7).
b. Delay designs for later segments to provide resources to critical path.

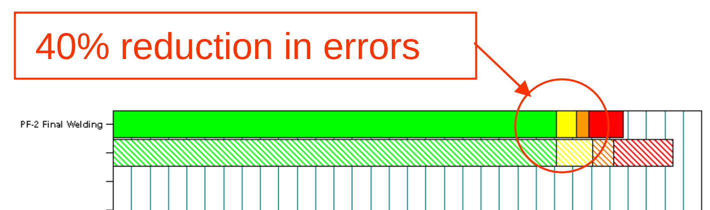
Results: Manufacturing Skills and Processes

1. **Case Summary**
   a. Ship to KSC Date: **October 10 2008.**
   b. Welder experience increases over time.
   c. Utilize Weld Machines for critical welds.
   d. WIP space / move tasks off stands.
2. **Organizational Impacts**
   a. Manufacturing resource backlogs are **< 2 weeks** (less errors, faster work).
   b. Reduced facility competition increases pressure on assembly resources.
   c. Facility competition drives **> 30 days work backlog.**



Conclusions

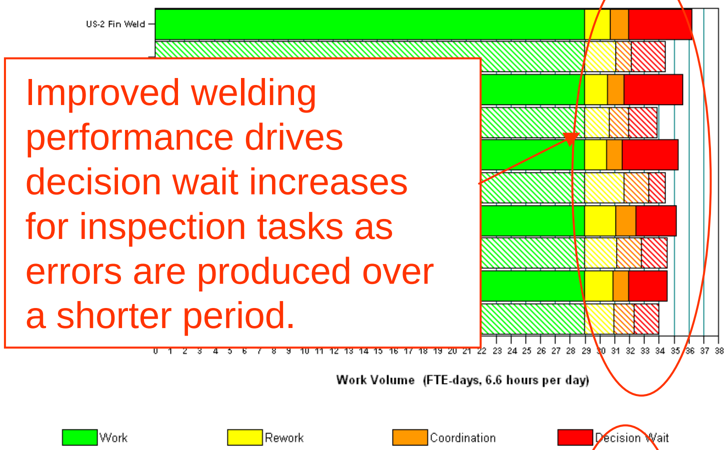
a. Crew based assembly reduces schedule delay by **~4 months.**
b. Weld Machines further improve delay by **~1 month.**
c. Weld Machines alone reduce schedule pressure by **~3 months.**
d. Provide WIP space; move Secondary Structure Assembly, Painting, and Clock and Mate to Bldg 333 (**saves ~30 days of schedule delay**).

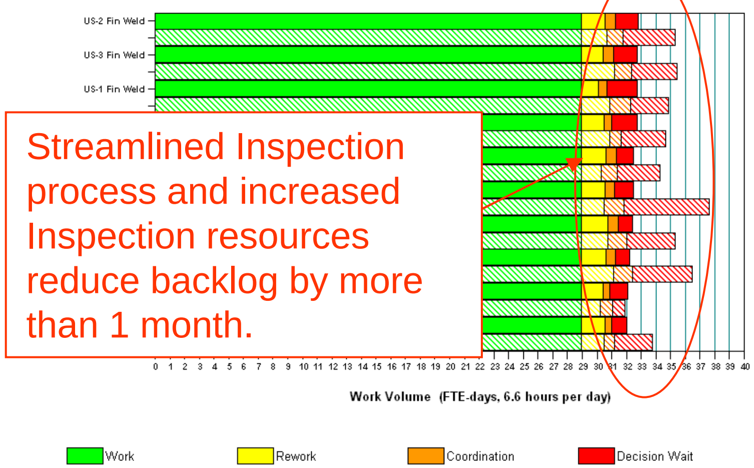


Task (PF-2 Final Weld)	Errors	Ignored	Corrected	Reworked
Baseline	4.8	0.7	1.5	2.6
Weld Machine	3	0.3	1.1	1.6

Manufacturing Organizational Requirements

1. **Case Summary**
    a. Ship to KSC Date: **September 1 2008.**
    b. Crew based segment manufacture.
    c. Utilize Weld Machines for critical welds.
    d. Increase Manufacturing and Inspection resources.
2. **Organizational Impacts**
    a. Increased Welder **(+4)** and Fabricator **(+2)** resources reduces schedule.
    b. Stand competition is reduced but still an issue for Beta and Alpha as schedule compresses.
    c. Decision Wait and Coordination volume due to **inspection delays drives schedule.**





Conclusions

a. Increase Fabricators (Total = 14) and Welders (Total = 8), or
b. Dedicate engineer to reduce decision cycle time to 24 hours, resource 1 inspector/stand and improve approval process.

Implement Crew Based Fabrication and Assembly
- **4 dedicated high skill/experience Welders using Weld Machines (Bldg 50)**
- **12 Fabricators (8-12 Bldg 50, 0-4 Bldg 333)**

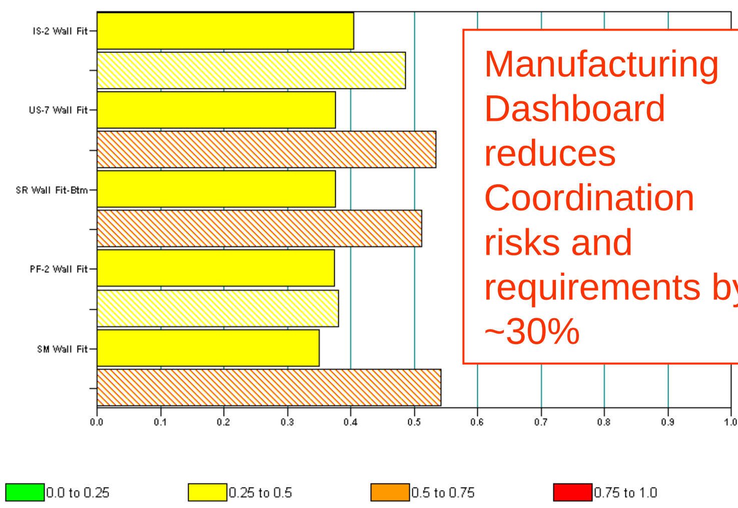
Accelerate Inspection Process
- **1 dedicated inspection engineer**
- **24 hour review process for NDE**

Communication and Work Flow Sensitivities

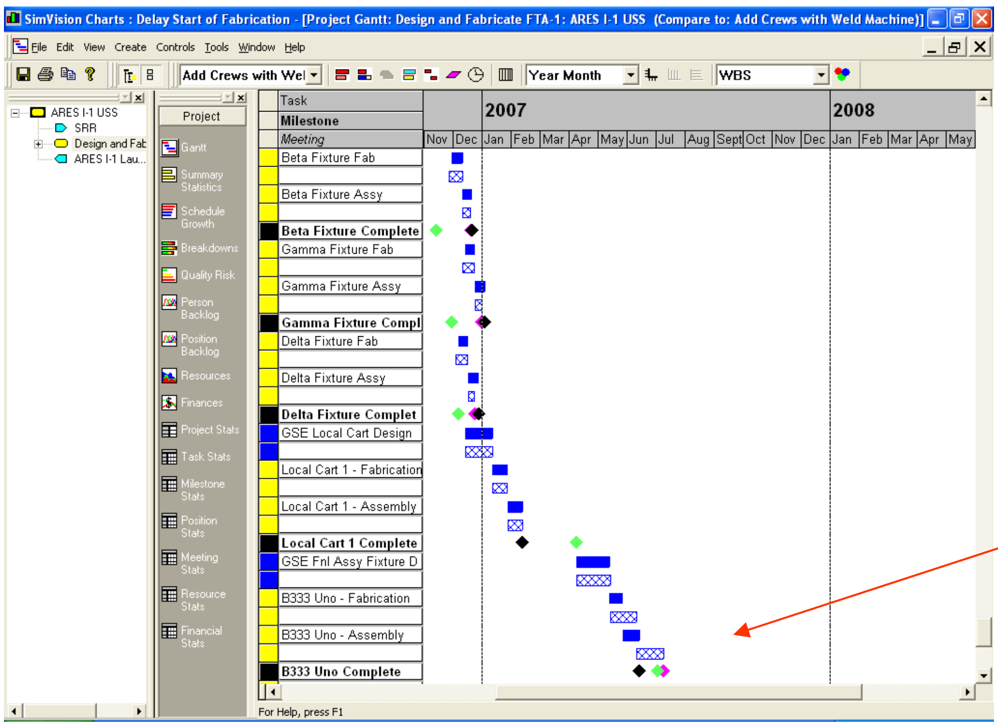
Conclusions

a. Improved coordination reduces schedule pressure by **2 weeks.**

b. Focusing on early segment design while permitting fabrication of low risk items does not delay final delivery date to KSC.



Manufacturing Dashboard reduces Coordination risks and requirements by ~30%



Delay of Segment Fabrication to July 1, 2007 permits PF's, DIS's and other Fabrication (e.g., GSE) steps to proceed with reduced competition for resources.

Summary of SimVision Findings

1. **Resource backlogs and facility competition drive schedule delays.**
2. **Early design backlogs pressure start of fabrication for early segments.**
3. **Solving the facility and process issues shifts the bottleneck risk to the organization.**
   a. Centralized decision making and formalized communication increases risk of delays and need for coordination.
   b. Coordination and communication risks rise as facility bottlenecks are removed.
4. **Specializing resources and tying them to tasks reduces Schedule pressure but increases need for Coordination.**
   a. Competition for facilities (stands and floor space) will put stress (overtime, rework, quality issues) on the organization to maintain schedule.
   b. System must be developed to coordinate the required highly choreographed manufacturing flow.

Summary of SimVision Recommendations

1. **Accelerate designs for Pathfinder-2 and early Segments (e.g., US-2/3/4/6/7).**
2. **Delay designs for later segments to provide resources to critical path.**
3. **Operate a crew based manufacturing organization.**
   - 4 Welders with Weld Machines (1 additional Weld Machine dedicated to rolling machine).
   - 12 Fabricators (distributed across fabrication and assembly in Bldg 50 and 333).
   - 4 Segment Assemblers (Bldg 333 super segment assembly).
   - Increase welding skills (all critical welds made by weld machines) and develop welding experience (crew based assembly).
4. **Begin fabrication of low risk items as early as possible (> 2 weeks).**
5. **Plan for *in process* holding space for parts (2 weeks), flanges (8) and segments (1).**
6. **Plan to relocate Clock and Mate tasks for middle and late segments to Bldg 333.**
7. **Dedicate 1 engineer (on site), resource 1 inspector/stand and improve approval process (<24 hrs) to minimize schedule impact of inspection tasks.**

Project's Take Away Recommendations

1. **Adopt mechanized welding approach with goal of minimizing weld defects and subsequent rework.**
   - Project Response: Accepted. Agrees with EWI recommendations. Mechanized MIG welding now baselined for Skin-Skin and Flange-Skin welds.
2. **Shift design resources to finish common segment design ASAP.**
   - Project Response: Accepted. Common Segments US-2, 3, 4, 6, 7 focus of first incremental USS Critical Design Review. Three serial CDR's planned out.
3. **Adopt crew based approach to maximize crew skill level.**
   - Project Response: Accepted. Professional welders obtained via support contract.
4. **Implement schedule dashboard to increase visibility of segment manufacturing flow to team and labor on floor.**
   - Project Response: Accepted. Dashboard one of several metrics used to communicate and track schedule. Daily Standup and Material Review Board (MRB) meetings setup.
5. **Implement flange storage recommendations.**
   - Project Response: Accepted. Lay down area in west end of AMF to be utilized.
6. **Study moving clock/mate/match drill and secondary structure to Building 333.**
   - Project Response: Partially accepted. Mate space carved out in AMF, plus additional processing (painting, internal access structure installation) required after clock/mate/match drill that is better suited for AMF.

A Look Backward: Benchmarking Simulation Against Reality

Simulation Prediction	Actual Result
Optimum Staffing: 4-6 welders, 8-12 fabricators	Validated: Steady State Staffing (Per Shift) 6 welders, 9 fabricators
Two shift operation required to meet schedule.	Validated: Project implemented two shift ops from outset.
Accelerate early Common Segment design and delay Complex Segment design.	Validated: Three serial critical design cycles/reviews implemented, to feed three serial manufacturing Charges.
Increase welding skills and experience, utilize mechanized welding to minimize defect rate.	Validated: Had to contract out to obtain welders with sufficient skill. Once obtained, mechanized welding was no longer needed!
Plan for in process holding area for machined parts (flanges, tangs, lugs).	Validated: Need for more floor space drove set up of Temp Storage Facility.
Dedicate staff to improve AMF floor coordination and reduce rework decision making time to 24 hrs max.	Validated: Floor Director position created per shift; Segment Lead Engineer positions created; MRB set up to meet daily.